<u>CLAIMS:</u>

What is claimed is:

1. For an image to be re-sampled, a method of performing spatial interpolation at a pixel position of a resampling line, said pixel position immediately below pixel x[0] of a first line comprising pixels x[-n] to x[n], said pixel position also immediately above pixel y[0] of a second line comprising y[-n] to y[n], said method comprising the steps of:

for k = 0 to 2n, assigning a numerical value A[k] to a direction D[k] that is established as a possible interpolation direction intercepting x[-n +k], said pixel position, and y[n - k], wherein said A[k] is defined for indicating the likelihood of an edge crossing said pixel position along said D[k] by quantifying the degree of similarity between a pixel segment seg[k,x]= {x[-n+k –c], … , x[-n +k +c]} from said first line and a pixel segment seg[k,y]={y[n – k –c], …, y[n – k +c]} from said second line, said first and said second segments approximately symmetric about said pixel position;

selecting from D[0] to D[2n] a first direction D[m] whose assigned A[m] indicates the highest likelihood of an edge crossing said pixel position along said D[m];

performing a segment analysis on a symmetric segment pair seg[m,x] and seg[m,y] associated with D[m], said segment analysis adapted to verify said symmetric segment pair as belonging to an edge crossing said pixel position, said seg[m,x] and seg[m,y] symmetrically located with respect to said pixel position; and

in response to said D[m] having been verified by said segment analysis, performing spatial interpolation at said pixel position along said D[m].

2. The method of Claim 1, wherein for $k = 0$ to $2n$,

said $A[k] = \Sigma_{r=-c \text{ to } c}\ f(\ P(x[-n + k + r]), P(y[n - k + r])\ )$,

wherein said function P is adapted to assign a pixel value to every pixel.

3. The method of Claim 2, wherein for $k = 0$ to $2n$,

said $A[k] = \Sigma_{r=-c \text{ to } c}\ | P(x[-n + k + r]) - P(y[n - k + r]) |$

is proportional to the expectation of said function P as a random variable function, wherein said $A[m]$ is the smallest element of $\{A[0], A[1], \ldots A[2n]\}$.

4. The method of Claim 2, wherein for $k = 0$ to $2n$,

said $A[k] = \Sigma_{r=-c \text{ to } c}\ | P(x[-n + k + r]) - P(y[n - k + r]) |^2$

is proportional to the variance of said function P as a random variable function, wherein said $A[m]$ is the smallest element of $\{A[0], A[1], \ldots A[2n]\}$.

5. The method of Claim 2, wherein for $k = 0$ to $2n$,

said $A[k] = \Sigma_{r=-c \text{ to } c}\ 1/(| P(x[-n + k + r]) * P(y[n - k + r]) |)$

is proportional to the cross correlation of said function P as a random variable function, and wherein said $A[m]$ is the smallest element of $\{A[0], A[1], \ldots A[2n]\}$.

6. The method of Claim 1, wherein for $k = 0$ to $2n$,

said $A[k] = J(\ g(x[i]), g(y[j]))$,

$i = -n+k - c$ to $-n + k + c$, and $j = n - k - c$ to $n - k + c$, wherein functions J and g can be chosen in accordance with the application at hand.

7. The method of Claim 6, wherein said function g is the Fourier transform of P acting on pixels belonging to the symmetric segment pair seg[k,x] and seg[k,y] associated with D[k], for k = 0 to 2n.

8. The method of Claim 6, wherein said function g is the wavelet transform of P acting on pixels belonging to the symmetric segment pair seg[k,x] and seg[k,y] associated with D[k], for k = 0 to 2n.

9. The method of Claim 6, wherein for motion pictures, said function g(x[i]) = q(P(x[i]), motion_data(x[i])) acting at a pixel x[i] is equal to a combination q of pixel value function P acting at said pixel x[i] and the motion data information at said pixel x[i]belonging to the symmetric segment pair associated with D[k], for k = 0 to 2n.

10. The method of Claim 1, wherein said segment analysis comprises the step of:

performing a peak/valley count test to verify that the total number of peaks and valleys in a graph graph[m,x] assigned to D[m] does not exceed 1, and that the total number of peaks and valleys in a graph graph[m,y] assigned to D[m] does not exceed 1, wherein said graph[m,x] comprises { x[u], P(x[u]) ; for u = (-n + k)+(-n + k) to 0 }, and wherein said graph[m,y] comprises { y[v], P(y[v]); for v = 0 to (n - k) + (n -k) }.

11. The method of Claim 2, wherein said segment analysis comprises the step

of

performing a pixel value difference test to verify that none of said 2c + 1 summands {f(P(x[-n +m + r]), P(y[n - m + r]); r = -c to c} of A[m] exceeds a pre-defined threshold value.

12. The method Claim 2, wherein said segment analysis comprises the steps of:

performing a peak/valley count test to verify that the total number of peaks and valleys in a graph graph[m,x] assigned to D[m] does not exceed 1, and that the total number of peaks and valleys in a graph graph[m,y] assigned to D[m] does not exceed 1, wherein said graph[m,x] comprises { x[u], P(x[u]) ; for u = (-n + k)+(-n + k) to 0 }, and wherein said graph[m,y] comprises { y[v], P(y[v]); for v = 0 to (n - k) + (n -k) }; and

performing a pixel value difference test to verify that none of said 2c + 1 summands {f(P(x[-n +m + r]), P(y[n - m + r]); r = -c to c} of A[m] exceeds a pre-defined threshold value.

13. The method of Claim 1, further comprising the step of:

in response to said D[m] having failed said segment analysis test, performing spatial interpolation at said pixel position along a default interpolation direction.

14. The method of Claim 13, wherein said default interpolation direction intercepts said pixel position, thereby forming approximately a 45-degree angle at said resampling pixel.

15. The method in any of Claims 3-6, wherein said 2n = 8, wherein said c = 3, and wherein said pixel value assigned by P is luminance value.

16. The method of Claim 1, comprising the step of:

performing a cross check test to verify that for a second direction D[h] whose slope is vertical or is of opposite sign from the slope of D[m], an absolute difference between A[h] and A[m] is less than a pre-defined threshold, and wherein D[m] is disqualified as an interpolation direction for said pixel position if said absolute is not less than said pre-defined threshold; and

performing post processing by adjusting the interpolated value of said pixel position according to the interpolated value of said pixel position and the pixel values of pixels neighboring said pixel position.

17. The method of Claim 1, comprising the step of:

performing an extreme value analysis on graph of A[t] as t varies from 0 to 2n to detect a first case wherein said A[m] is a minimum with m is not equal to 0 or 2n and the slope of A[t] changes sign only once from negative to positive; a second case wherein said A[m] is a minimum with m equals to 0 and the sign of slope of A[t] remains positive; or a third case wherein said A[m] is a minimum with m equals to 2n and the sign of slope of A[t] remains negative; and wherein D[m] is disqualified as an interpolation direction for said pixel position if none of said three cases is detected; and

performing post processing by adjusting the interpolated value of said pixel position according to the interpolated value of said pixel position and the pixel values of

pixels neighboring said pixel position.

18. For an image to be re-sampled, a system of performing spatial interpolation at a pixel position of a resampling line, said pixel position immediately below pixel x[0] of a first line comprising pixels x[-n] to x[n], said pixel position also immediately above pixel y[0] of a second line comprising y[-n] to y[n], said system comprising:

an evaluation unit adapted for assigning for k = 0 to 2n a numerical value A[k] to a direction D[k] that is established as a possible interpolation direction intercepting x[-n +k], said pixel position, and y[n - k], wherein said A[k] is defined for indicating the likelihood of an edge crossing said pixel position along said D[k] by quantifying the degree of similarity between pixel segments seg[k,x]= {x[-n+k –c], … , x[-n +k +c]} and seg[k,y]={y[n – k –c], …, y[n – k +c]};

a selection unit coupled to said evaluation unit, said selection unit adapted for selecting from D[0] to D[2n] a first direction D[m] whose assigned A[m] indicates the highest likelihood of an edge crossing said pixel position along said D[m];

a segment analysis unit coupled to said selection unit, said segment analysis unit adapted to performing a segment analysis on a symmetric segment pair seg[m,x] and seg[m,y] associated with D[m] to verify that the micro-structure of said seg[m,x] and seg[m,y] is consistent with features of an edge, said seg[m,x] and seg[m,y] symmetrically located with respect to said pixel position ; and

an interpolation unit adapted for performing spatial interpolation at said pixel position along said D[m] in response to said D[m] having been verified by said segment

analysis unit.

19. The system of Claim 18, for $k = 0$ to $2n$,

said $A[k] = \Sigma_{r = -c \text{ to } c}\ f(\ P(x[-n + k + r]), P(y[n - k + r\ ])\ )$,

wherein said function P is adapted to assign a pixel value to every pixel.

20. The system of Claim 19, wherein said segment analysis unit comprises:

a peak/valley count test unit adapted for performing a peak/valley count test to verify that the total number of peaks and valleys in a graph graph[m,x] assigned to D[m] does not exceed 1, and that the total number of peaks and valleys in a graph graph[m,y] assigned to D[m] does not exceed 1, wherein said graph[m,x] comprises $\{\ x[u], P(\ x[u])\ ;$ for $u = (-n + m)+(-n + m)$ to $0\ \}$, and wherein said graph[m,y] comprises $\{\ y[v], P(\ y[v]);$ for $v = 0$ to $(n - m) + (n - m)\ \}$.

21. The system of Claim 19, wherein said segment analysis unit comprises:

a pixel value difference test unit adapted for performing a pixel value difference test to verify that none of said $2c + 1$ summands $\{f(\ P(x[-n + m + r]), P(y[n - m + r\ ]);\ r = -c$ to $c\}$ of A[m] exceeds a pre-defined threshold value.

22. The system of Claim 19, wherein said segment analysis unit comprises:

a peak/valley count test unit adapted for performing a peak/valley count test to verify that the total number of peaks and valleys in a graph graph[m,x] assigned to D[m] does not exceed 1, and that the total number of peaks and valleys in a graph graph[m,y]

assigned to D[m] does not exceed 1, wherein said graph[m,x] comprises { x[u], P(x[u]) ; for u = (-n + k)+(-n + k) to 0 }, and wherein said graph[m,y] comprises { y[v], P(y[v]); for v = 0 to (n - k) + (n -k) }; and

a pixel value difference test unit adapted for performing a pixel value difference test to verify that none of said 2c + 1 summands {f (P(x[-n +m + r]), P(y[n - m + r]); r = -c to c} of A[m] exceeds a pre-defined threshold value.

23. The system of Claim 19, wherein said for k = 0 to 2n,

said $A[k] = \Sigma_{r=-c \text{ to } c} \mid P(x[-n + k + r]) - P(y[n - k + r]) \mid$

is proportional to the expectation of said function P as a random variable function, wherein said A[m] is the smallest element of {A[0], A[1], ... A[2n]}.

24. The system of Claim 19, wherein for k = 0 to 2n,

said $A[k] = \Sigma_{r=-c \text{ to } c} \mid P(x[-n + k + r]) - P(y[n - k + r]) \mid^2$

is proportional to the variance of said function P as a random variable function, wherein said A[m] is the smallest element of {A[0], A[1], ... A[2n]}.

25. The system of Claim 19, wherein for k = 0 to 2n,

said $A[k] = \Sigma_{r=-c \text{ to } c}\, t \mid P(x[-n + k + r]) * P(y[n - k + r]) \mid$

is proportional to the correlation of said function P as a random variable function, and wherein said A[m] is the largest element of {A[0], A[1], ... A[2n]}.

26. The system of Claim 18, wherein for k = 0 to 2n,

said $A[k] = J(g(x[i]), g(y[j]))$,

$i = -n+k-c$ to $-n+k+c$, and $j = n-k-c$ to $n-k+c$, wherein functions J and g can be chosen in accordance with the application at hand.

27. The method of Claim 26, wherein said function g is the Fourier transform of P acting on pixels belonging to the symmetric segment pair seg[k,x] and seg[k,y] associated with D[k], for $k = 0$ to $2n$.

28. The method of Claim 26, wherein said function g is the wavelet transform of P acting on pixels belonging to the symmetric segment pair seg[k,x] and seg[k,y] associated with D[k], for $k = 0$ to $2n$.

29. The method of Claim 26, wherein for motion pictures, said function $g(x[i]) = q(P(x[i]), \text{motion\_data}(x[i]))$ acting at a pixel x[i] is equal to a combination q of pixel value function P acting at said pixel x[i] and the motion data information at said pixel x[i]belonging to the symmetric segment pair associated with D[k], for $k = 0$ to $2n$.

30. The system in any of Claims 23-26, wherein said $2n = 8$, wherein said $c = 3$, and wherein said pixel value assigned by P is luminance value.

31. The system of Claim 18, wherein said interpolation unit is adapted for performing spatial interpolation at said pixel position along a default interpolation direction in response to said D[m] having failed said verification by said segment

analysis unit.

32. The system of Claim 31, wherein said default interpolation direction intercepts said pixel position, thereby forming approximately a 45-degree angle at said resampling pixel.

33. The system of Claim 18, further comprising:

a cross check test unit adapted for performing a cross check test to verify that for a second direction D[h] whose slope is vertical or is of opposite sign from the slope of D[m], an absolute difference between A[h] and A[m] is less than a pre-defined threshold, and wherein D[m] is disqualified as an interpolation direction for said pixel position if said absolute difference is not less than said pre-defined threshold..

34. The system of Claims 18, wherein said segment analysis unit comprises:

a peak/valley count test unit adapted to verify that the total number of peaks and valleys in a graph graph[m,x] assigned to D[m] does not exceed 1, and that the total number of peaks and valleys in a graph graph[m,y] assigned to D[m] does not exceed 1, wherein said graph[m,x] comprises $\{ x[u], P(x[u]) ; \text{for } u = (-n + k)+(-n + k) \text{ to } 0 \}$, and wherein said graph[m,y] comprises $\{ y[v], P(y[v]); \text{for } v = 0 \text{ to } (n - k) + (n -k) \}$.

35. The system of Claim 19, wherein said segment analysis unit comprises:

a pixel value difference test unit adapted to verify that none of said $2c + 1$ summands $\{f(P(x[-n +m + r]), P(y[n - m + r]); r = -c \text{ to } c\}$ of A[m] exceeds a pre-

defined threshold value.

36. The system of Claim 19, wherein said segment analysis unit comprises:

a peak/valley count test unit adapted to verify that the total number of peaks and valleys in a graph graph[m,x] assigned to D[m] does not exceed 1, and that the total number of peaks and valleys in a graph graph[m,y] assigned to D[m] does not exceed 1, wherein said graph[m,x] comprises { x[u], P(x[u]) ; for u = (-n + k)+(-n + k) to 0 }, and wherein said graph[m,y] comprises { y[v], P(y[v]); for v = 0 to (n - k) + (n -k) }; and

a pixel value difference test unit adapted to verify that none of said 2c + 1 summands {f (P(x[-n +m + r]), P(y[n - m + r]); r = -c to c} of A[m] exceeds a pre-defined threshold value.

37. The system of Claim 18, further comprising:

an extreme value analysis unit 333 is adapted to detect in a graph of A[t] as t varies continuously from 0 to 8 a first case wherein said A[m] is a minimum with m is not equal to 0 or 8 and the slope of A[t] changes sign only once from negative to positive; a second case wherein said A[m] is a minimum with m equals to 0 and the sign of slope of A[t] remains positive; or a third case wherein said A[m] is a minimum with m equals to 8 and the sign of slope of A[t] remains negative; and wherein D[m] is disqualified if A[m] does not fit any one of said three cases.

38. The system of Claim 18, further comprising:

a post processing unit adapted for performing post processing by adjusting the interpolated value of said pixel position according to the interpolated value of said pixel

position and the pixel values of pixels neighboring said pixel position.

39. A method for performing spatial interpolation at a pixel position on a resampling line of an image to be re-sampled, said method comprising the steps of:

establishing a plurality of possible interpolation directions intercepting at said pixel position by using a first plurality of pixels from a first line immediately above said resampling line, and by using a second plurality of pixels from a second line immediately below said resampling line;

for each of said plurality of possible interpolation directions, quantifying the likelihood of each said possible interpolation direction for being an interpolation direction to be used by assigning a numerical value to each of said plurality of possible interpolation directions;

from said plurality of possible interpolation directions, selecting an interpolation direction that has a minimum assigned value;

performing a plurality of verifications to rule out erroneous selection of said selected interpolation direction; and

performing spatial interpolation along said selected interpolation direction if said selected interpolation direction passes said plurality of verifications.

40. The method of Claim 39, further comprising the step of:

performing spatial interpolation along a default interpolation direction intercepting said pixel position if said selected interpolation direction does not pass said plurality of verifications.

41. A method for rendering an edge having a non-zero slope that intercepts a pixel position of a resampling line in an image to be re-sampled, said method comprising the steps of:

detecting said edge along a plurality of pre-defined directions intercepting effectively at said pixel position by selecting a pre-defined direction based on a numerical ranking assigned to said plurality of pre-defined directions, wherein each of said pre-defined directions has a non-zero slope;

verifying said selected direction for performing spatial interpolation at said pixel position using pixels that lie along said selected direction; and

in response to said selected direction passes said verifying step, performing spatial interpolation at said pixel position using pixels that lie along said selected direction.

42. The method of Claim 41, further comprising the step of:

in response to said selected direction not passing said verifying step, performing spatial interpolation at said pixel position using pixels that lie along a default interpolation direction, said default interpolation direction intercepting said pixel position.

43. A method for re-sample an image by spatial interpolation, said method comprising the steps of:

assigning n numerical value respectively to n pre-defined interpolation directions that intercept effectively at a pixel position in a resampling line, forming respectively n non-zero angles with said resampling line;

selecting an interpolation direction from said n interpolation directions by ranking said n assigned numerical values;

eliminating erroneous selection of selected interpolation direction by performing a plurality of verification tests on said selected interpolation direction; and

in response to the selected interpolation direction passing all verifications, performing spatial interpolation along said selected interpolation direction.

44. The method of Claim 43, further comprising the step of:

in response to the selected interpolation direction disqualified by any of verification tests, performing spatial interpolation along a default interpolation direction.

45. The method of Claim 44, wherein said default interpolation direction forms a 45 degree angle with said resampling line.

46. The method of Claim 43, wherein each of said n numerical values is generated using pixel values from a first pixel segment belonging to a first line immediately above said resampling line, and pixels values from a second pixel segment belonging to a second line immediately below said resampling line, said first and said second pixel segments approximately symmetric about said pixel position.

47. The method of Claim 43, wherein the assigned numerical value of said selected interpolation ranks as the smallest among said n numerical assigned values.

48. The method of Claim 43, wherein said selected interpolation direction fails a first test of said plurality of verification tests if multiple edges are found crossing at said pixel position, wherein said selected interpolation direction fails a second test of said plurality of said verification tests if the number of peaks and valleys is greater than one, and wherein said selected interpolation direction fails a third test of said plurality of verification tests if any of a plurality of summands adapted to define said assigned value of said selected interpolation direction exceeds a pre-defined threshold value.

49. A system for image resample by spatial interpolation, said system comprising:

an evaluation unit adapted to assign a numerical value to each of a plurality of pre-defined interpolation directions that intercept effectively at a pixel position in a resampling line of said field;

a selection unit coupled to said evaluation unit, said selection unit adapted to select an interpolation direction from said plurality of pre-defined interpolation directions by ranking said plurality of assigned numerical values;

a segment analysis unit comprising a plurality of verification units coupled to said second unit, said verification units adapted to eliminate erroneous selection of said selected interpolation direction by performing verifications on said selected interpolation direction; and

an interpolation unit coupled to said unit, wherein said interpolation unit is adapted to perform spatial interpolation at said pixel position along the selected interpolation direction in response to the selected interpolation direction passing all

verifications.

50. The system of Claim 49, wherein said interpolation unit is adapted to perform spatial interpolation at said pixel position along a default interpolation direction in response to the selected interpolation direction disqualified by any of said plurality of verification unit.